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# How Cheap Talk Enhances Efficiency in Public Goods Games\*

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## Abstract

This paper uses a Bayesian mechanism design approach to investigate the effects of communication in a threshold public goods game. Individuals have private information about contribution costs. If at least some fraction of the group make a discrete contribution, a public benefit accrues to all members of the group. We experimentally implement three different communication structures prior to the decision move: (a) simultaneous exchange of binary messages, (b) larger finite numerical message space and (c) unrestricted text chat. We obtain theoretical bounds on the efficiency gains that are obtainable under these different communication structures. In an experiment with three person groups and a threshold of two, we observe significant efficiency gains only with the richest of these communication structures, where participants engage in unrestricted text chatting. In that case, the efficiency bounds implied by mechanism design theory are achieved.

JEL Classification Numbers: C72, C92, D82, D83, H41

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# 1 Introduction

We investigate how communication influences public good provision in a threshold public goods game with private information about contribution costs. The provision of threshold public goods combines free riding incentives with a coordination problem, both of which are further complicated if there is private information. Pre-play communication between agents provides a potential path to overcoming these problems, but whether communication is effective in practice, and how its effectiveness depends on the structure of communication and private information, are questions that remain largely unanswered both theoretically or empirically. This paper makes three contributions to addressing these questions. First, by modeling the game with communication as a Bayesian mechanism design problem, we are able to develop some theoretical bounds on the gains that can be attained from different pre-play communication protocols. Second, we show how these bounds depend on the distribution of private information and on the communication structure - in particular the richness of the message space. Third, we design and conduct an experiment where we vary both the communication structure and the distribution of private information.

We present several results. First, in the experiment we find that communication has significant beneficial effects only when the group members communicate in natural language. Restricting subjects to coarser message spaces, such as a binary message space or to one-time reports of their private information partially solves the coordination problem, but not enough to produce a statistically significant improvement compared with groups that were not allowed to communicate. A second finding is that the effectiveness of pre-play communication depends on the distribution of private information. In half of our data, it was common knowledge that all subjects had contribution costs that were less than or equal to the benefit of the public good, implying that it was common knowledge that, for every subject, it is optimal to contribute if their contribution is pivotal for the provision of the public good. In the other half of the data, the distribution of contribution costs was such that its support included costs that exceeded the benefit, and hence it was common knowledge that any group member with such a high cost has a dominant strategy to free ride. In this second variant, natural language communication was much less effective and helped only after significant experience was gained. This sharp difference in the effect of communication is also reflected in the theoretical bounds implied by the optimal mechanism. A binding individual rationality constraint, which is present only in the high cost treatment, sharply reduces the amount of public good provision that can be supported. Thus, we establish both theoretically and behaviorally, that the effectiveness of private communication depends on both the richness of the message space and the distribution of private information.

To keep the analysis and experimental design simple, players in the threshold public goods game

have only a binary choice - to contribute or not, and the public good is produced if and only if at least some threshold number of group members choose to contribute, with the threshold being less than the group size. This class of games includes the social dilemmas studied by Dawes et al. (1986), Offerman et al. (1998), and Palfrey and Rosenthal (1991), and shares similar strategic elements to the volunteer’s dilemma, entry games, and participation games studied by Goeree and Holt (2005). Contributions are non-refundable, so that an efficient outcome requires that exactly the threshold number of contributions are made. Too many contributions or too few contributions reflect coordination failure. Because the group members have different contribution costs, (ex ante) efficient provision also requires that the contributions are made only by the lowest cost members of the group. Thus heterogeneity of contribution costs create a second kind of coordination problem, and private information exacerbates this latter coordination problem with an incentive compatibility problem. In all cases there is a free rider problem, in the sense that any contributing member would prefer to switch roles with any non-contributing member, regardless of their contribution costs.

The three forms of pre-play communication we consider were carefully chosen. The coarsest possible message space we consider is *binary*.<sup>1</sup> In the communication stage with binary messages, each group member announces an “intention” to either contribute or not, which is then followed by a simultaneous-move contribution stage with binding decisions, so the communication stage can be viewed as a direct signal about contribution in the final stage of the game or alternatively as a “practice game”, where one’s first round contribution decision has no direct payoff consequences. The second message space is somewhat richer, where group members simultaneously announce any number in the support of the distribution of contribution costs, thus mimicking a direct mechanism (but without a mediator), which is then followed by a contribution stage with binding decisions. The richest communication structure we consider is natural language communication where the communication stage consists of a fixed time period during which chat messages can be broadcast continuously among the group members. After the chat stage, binding contribution decisions are made simultaneously by all group members. In addition to varying the structure of communication, we varied the distribution of contribution costs. In the “ $C = 1$ ” condition, it is always incentive compatible for the two lowest cost individuals to contribute and thus provide the public good. In the “ $C = 1.5$ ” condition, incentive compatibility problems could result in the good not being provided even though provision was socially optimal.

The remainder of the paper is organized as follows. The related literature is reviewed in Section 2. Section 3 specifies the experimental design, theoretical framework and the central hypotheses. Section 4 presents the experimental results and analysis. The last section concludes.

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<sup>1</sup>A binary message space was also explored in past work (Palfrey and Rosenthal (1991)).

## 2 Related Literature

### Theory

That selfish players may choose to reveal private information through costless and non-binding communication or cheap talk, and that such revelation can lead to efficiency gains, has been shown by Crawford and Sobel (1982), and the problem has been formulated in generality by Forges (1986) and Myerson (1986). Palfrey and Rosenthal (1991) were the first to investigate the effects of cheap talk in a model where players have private information about costs to contribute towards the provision of a public good. They considered a ‘threshold public good game’ where provision requires contributions from at least a minimum number of people. Using a binary communication setting, they showed that perfect coordination is not Bayesian-incentive compatible and that players have weak incentives to free-ride in these kind of situations, but they show the existence of communication equilibria that lead to higher efficiency. Using a model of continuous contributions with two privately informed players, Agastya et al. (2007) show theoretically that individuals do not have an incentive to contribute to the public good without communication, but binary communication gives them incentives to provide the good with positive probability.

Kawamura (2011) uses an  $n$ -player setting and shows that there always exists an equilibrium where binary messages are credible and that, when  $n$  goes to infinity, the equilibrium with binary communication is the most efficient one. Costa and Moreira (2012) find that a truthful equilibrium of the communication game with a binary message space cannot be Pareto dominated by any truthful equilibrium with any finite message space. They argue that this is because players use a threshold rule to make contribution decisions and in any situation with more than one contribution threshold, they have incentives to understate their types and thereby free-ride on their partners’ investments.

### Experiments

Threshold public goods games have been implemented in the laboratory by few researchers. Bagnoli and McKee (1991) find that the Pareto efficient outcome emerges when the cost of the good, the payoffs to those in the group, and the initial wealth positions of those in the group are common knowledge. They report that if the collective valuation of a group exceeds the cost of the good, the members of the group voluntarily contribute exactly the cost of the public good. Van de Kragt et al. (1983) show that free communication via general, unstructured discussion produces better outcomes than the same games conducted without communication in the context of public goods games similar to the one implemented by us. The message space was the entire English language and speaking order was entirely

endogenous, occurring in continuous time with face-to-face communication. An important distinction from our game is that the contribution costs were equal for all players and common knowledge. Thus, Van de Kragt et al. (1983) eliminated two important impediments to coordination - private information and heterogeneity in costs. More structured cheap talk environments with public goods have been examined by Smith (1980) and Ferejohn et al. (1982). They considered the problem of designing market-like auction processes for the provision of discrete public good.

Palfrey and Rosenthal (1991) report results from games similar to the three-person threshold games considered in this paper and conclude that in the absence of communication, behavior is closely approximated by the Bayesian equilibrium predictions, except that subjects contribute slightly more often than predicted. In other experiments, they implemented a binary message stage prior to the decision making stage and found that this type of communication fails to provide more efficient outcomes than the ‘no communication’ outcome. They also found that subjects use a cutoff decision rule when it is optimal to do so in the ‘no communication’ treatment, while players’ behavior is less systematic with communication.

Several experiments have implemented different forms of communication structures to evaluate the effect of cheap talk in other games. Cooper et al. (1992) studied one-way communication and two-way communication in coordination games and concluded that allowing pre-play communication does not uniformly lead to the play of the Pareto-dominant Nash equilibrium. There are situations where one-way communication performs significantly better than two-way communication. In a standard repeated VCM<sup>2</sup> model, Bochet et al. (2006) vary the message space used in the cheap talk games and find that the treatment with exchange of numerical messages does not affect efficiency compared to the situation with no communication. However, both types of verbal communication, face-to-face and anonymous chat, increase cooperation<sup>3</sup>. Costa and Moreira (2012) implement a two-person contribution game and find evidence that larger finite message spaces do not provide efficiency gain relative to the binary communication structure.

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<sup>2</sup>Under a voluntary contribution mechanism (VCM), individuals voluntarily allocate their initial holdings of resources into the production of public and private goods. Certain assumptions on the payoffs and utilities are made such that there exists a dominant strategy to not contribute anything to the production of the public good and “free-ride” on the contributions of others.

<sup>3</sup>The result that face-to-face communication increases contributions in repeated VCM experiments has been shown by various researchers, including Isaac and Walker (1988), Cason and Khan (1999), Brosig et al. (2003), Belianin and Novarese (2005). Ostrom and Walker (1991) also find the same result in repeated common property resource situations. More references are provided in a survey by Ledyard (1995).

### 3 Theoretical Framework

In this section, we use a mechanism design approach to develop theoretical bounds on the range of behavior and efficiency that can be achieved under the different communication regimes. There are four sources of inefficiency that can arise. The first is wasteful undercontribution, which arises when exactly one individual contributes and the public good is not provided. The second is wasteful overcontribution, which arises when all three individuals contribute. The public good is provided, but could have been provided at lower cost. Both of these inefficiencies are coordination failures, and can also arise where there is no private information and all players have the same cost to contribution. The third source of inefficiency is the classic free rider problem, whereby the public good is not provided even though, given the cost realizations, it would be efficient to provide it. The fourth source of inefficiency arises when the public good is provided with exactly two contributors, but their costs are not the two lowest. In this section we explore the extent to which communication can mitigate the efficiency losses from these four sources of inefficiency.

#### The Environment

A group consisting of  $N$  persons is undertaking a project. Each group member is endowed with one indivisible unit of input, which may be either consumed or “contributed” to the production of the group project. The project succeeds if and only if at least  $K$  units are contributed. The value of the project to any individual is normalized to equal 1. The private value of the endowed unit of input to an individual  $i$  is denoted by  $c_i$ . Each individual  $i$  knows  $c_i$  but only knows that the other players’  $c$ ’s are independent random draws from a cumulative distribution distribution  $F$  on  $[0, C]$ , where  $F$  is common knowledge and  $C > 0$ .  $F$  is *admissible* if  $F(0) = 0$ ,  $F(C) = 1$  and  $F$  is continuously differentiable on  $[0, C]$ , and we assume throughout that  $F$  is admissible. The utility for player  $i$  with cost  $c_i$  is given by:

$$\begin{aligned} 1 + c_i & \text{ if } i \text{ does not contribute and at least } K \text{ others contribute} \\ c_i & \text{ if } i \text{ does not contribute and fewer than } K \text{ others contribute} \\ 1 & \text{ if } i \text{ contributes and at least } K - 1 \text{ other contributes} \\ 0 & \text{ if } i \text{ contributes and and fewer than } K - 1 \text{ others contribute} \end{aligned}$$

Formally the four sources of inefficiency are the following: *wasteful undercontribution*, where exactly  $k \in \{1, \dots, K-1\}$  individuals contribute and the public good is not provided; *excess contributions*, where exactly  $k \in \{K+1, \dots, N\}$  contribute; *underprovision*, where the public good is not provided

even though there exist  $K$  individuals such that the sum of their costs is less than  $N$  (the total social benefit of providing the public good); and *cost inefficiency*, where the public good is provided with exactly  $K$  contributors, but their costs are not the  $K$  lowest costs. We next explore the extent to which a benevolent mechanism designer can mitigate the ex ante welfare losses from these four sources of inefficiency.

### Baseline Lower Bound: Equilibrium Without Communication

We first consider the positive contribution symmetric Bayesian Nash equilibrium of the game without communication.<sup>4</sup> This is a relevant lower bound for efficiency for all four treatments, and provides the upper bound as well for the no-communication treatment.

This Bayesian equilibrium is characterized by a cutpoint strategy,  $c^*$ : player  $i$  contributes if and only if  $c_i \leq c^*$ . In our case with a uniform distribution of contribution costs,  $c^*$  solves the equation  $c^* = [2c^*(C - c^*)]/C^2$ . The left hand side is the opportunity cost of contributing for a player a private cost of  $c^*$  and the right hand side is the probability that the player's contribution is pivotal. In equilibrium these two are equal. Players with a cost below  $c^*$  are better off contributing, given others are using the  $c^*$  decision rule and players with private costs greater than  $c^*$  are better off not contributing. Individuals with a cost of exactly  $c^*$  are indifferent between contributing and not contributing. Thus, for  $C = 1$ , the equilibrium is  $c_{1,0}^* = .5$  and for  $C = 1.5$ , the equilibrium is  $c_{1.5}^* = .375$ . We consider these two values of  $C$  as we use these in our experiments.

### Upper Bound: Optimal Communication Equilibrium

With communication, many new additional equilibria arise. The most obvious class of equilibria are babbling equilibria, where the equilibrium strategies in the communication stage are such that no information is transmitted. In all of these equilibria, the behavior in the second stage is identical to the behavior in the game without communication, so these equilibria do not enhance efficiency. However, more interesting communication equilibria lead to higher ex ante payoffs for all players. Moreover, the set of communication equilibria of the game can depend on the message space and protocol of the communication stage. While there are multiple equilibria with communication<sup>5</sup>, in this section we identify efficiency bounds for each of the three communication protocols, and identify equilibrium strategy profiles that achieve these bounds. As introduced in section 1, the three communication protocols are binary communication, direct mechanism without a mediator through announcement of

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<sup>4</sup>There is also a zero contribution equilibrium that we ignore because it is unstable, as shown in Palfrey and Rosenthal (1991).

<sup>5</sup>Palfrey and Rosenthal (1991) characterize a class of equilibria in these games with binary communication.



a number in the support of the distribution of contribution costs and natural language communication through text chat.

Equilibrium outcomes would be fully efficient if there were a communication equilibrium that always resulted in the individuals with the lower two costs contributing while the individual with the highest cost does not contribute. This ‘*first best outcome*’, however, is not consistent with equilibrium when  $C = 1$  as there would be incentives to over report costs. Furthermore, if  $C = 1.5$  then it is not consistent with equilibrium because ex post individual rationality would be violated: specifically, this ‘*first best outcome*’ could not be achieved when one or both of the lower two costs are great than 1. Alternatively, in this  $C = 1.5$  environment one might hope that a ‘*constrained first best outcome*’ would be supportable by a communication equilibrium, where (a) individuals with the lower two costs only contribute if both of the lower two costs are less than or equal to 1, and (b) no one contributes if one or both of the lower two costs are higher than 1. However, this would clearly violate incentive compatibility, for the same reasons the first best is not incentive compatible for  $C = 1$ .

For the two communication mechanisms with essentially continuous message spaces (direct revelation and chat), we use mechanism design theory to characterize the optimal equilibrium. We model the communication game as direct mechanism in which we imagine that each individual independently submits a report of their private cost to the mechanism designer from the support of possible costs (either  $[0, 1]$  or  $[0, 1.5]$ ). The mechanism designer, after receiving all three reports, makes a recommendation to each player to either contribute or not. An incentive compatible and ex post individually rational mechanism is one in which, given the mechanism designer’s recommendation strategy (which may be randomized), it is optimal for each player to honestly report their true private cost and to obey the recommendation of the mechanism designer. Among this class of mechanisms we identify the symmetric one that optimizes the ex ante group payoff.<sup>6</sup> After this characterization, we turn to the binary communication games, where the characterization is different due to the restricted message space.

## The optimal mechanism design problem

In this section we characterize the ex ante efficient equilibrium of the game with communication between the players by first characterizing an optimal mechanism. Consider a direct mechanism  $(p, a)$  where  $p : [0, C]^N \rightarrow [0, 1]$  is the probability of provision as a function of the reported profile of values; and  $\{a_i : [0, C]^N \rightarrow [0, 1]\}_{i=1, \dots, N}$  is the (possibly random) profile of contribution assignments. In the mechanism design problem, the optimal mechanism must satisfy a number of constraints. First,

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<sup>6</sup>Symmetry is without loss of generality.

it must be incentive compatible, in the sense that it is a Bayesian equilibrium for all individuals to truthfully report their private information (cost of contribution). Second, feasibility requires that  $(p, a)$  satisfies an expected budget constraint. That is,  $(p, a)$  is feasible if and only if  $p(\mathbf{c}) \leq \frac{1}{K} \sum_{i=1}^N a_i(\mathbf{c})$ , for all profiles of individual costs,  $\mathbf{c} = (c_1, \dots, c_N)$ . That is the expected sum of the payments must be at least  $K$  times the probability the public good is produced. Third, in the actual contribution game that follows the communication stage, no individual can be forced to contribute if the payoff from contributing is negative. In particular, this requires at least that  $a_i(\mathbf{c}) = 0$  for all  $\mathbf{c} \in [0, C]^N$  such that  $c_i > 1$ . We refer to this as the *ex post individual rationality constraint*.<sup>7</sup> Without loss of generality we can restrict ourselves to symmetric mechanisms in these symmetric environments, so the  $p$  functions and the  $a$  functions are anonymous. We then work with the reduced form of the mechanism, denoted by  $(P, A)$ , where  $P : [0, C] \rightarrow [0, 1]$  is the expected probability of provision from an interim standpoint for an individual who has valuation  $c_i$ ; and  $A : [0, C] \rightarrow [0, 1]$  is the expected probability of  $i$  contributing from an interim standpoint for an individual who has valuation  $c_i$ . That is:

$$\begin{aligned} P(c) &= \int_{C_{-i}} p(c_i, c_{-i}) dF(c_{-i}) \\ A(c) &= \int_{C_{-i}} a(c_i, c_{-i}) dF(c_{-i}) \end{aligned}$$

Because feasibility implies that  $p(\mathbf{c}) \leq \frac{1}{K} \sum_{i=1}^N a_i(\mathbf{c})$ , for all  $\mathbf{c} \in [0, C]^N$ , the corresponding reduced form mechanism,  $(P, A)$ , also must satisfy the budget constraint in expectation, which can be written as:<sup>8</sup>

$$\frac{K}{N} \int_0^C P(c) f(c) dc \leq \int_0^C A(c) f(c) dc \quad (1)$$

We refer to a mechanism as *budget balanced* if (1) holds with equality. We next proceed by characterizing the optimal reduced form mechanism, in two different cost distributions, which are used in the experiment.

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<sup>7</sup>This is only a necessary condition for ex post individual rationality, but it is the only one that is relevant for our characterization.

<sup>8</sup>In principle, there is also the question about whether additional implementability conditions may impose further constraints on the problem, i.e., the question of whether the optimal reduced form mechanism can be feasibly implemented by a  $(p, a)$  mechanism. As it turns out, for this class of problems it is not an issue.

**Low cost distribution:  $C = 1$**

The  $C = 1$  case is the simplest case<sup>9</sup> because in any budget balanced mechanism, the ex post individual rationality constraint will not be binding. We will derive the optimal mechanism below, without imposing the ex post individual rationality constraint, and then show that the optimal mechanism is budget balanced and hence the ex post individual rationality constraint is not binding. Thus, for the case of  $C = 1$  the optimal mechanism is characterized as the solution to the following program:

$$\begin{aligned}
 & \max_{(P,A)} \int_0^1 U(c) dc \\
 & \text{subject to} \\
 & U(c) \geq P(c') - cA(c') \quad \forall c, c' \\
 & \frac{K}{N} \int_0^1 P(c) dc \leq \int_0^1 A(c) dc \\
 & 0 \leq P(c) \leq 1 \quad \forall c, \quad 0 \leq A(c) \leq 1 \quad \forall c
 \end{aligned} \tag{2}$$

where  $U(c) \equiv P(c) - cA(c)$  is the interim expected utility to an individual with private cost  $c$ .

The first constraint is incentive compatibility and the other constraints are feasibility. Following standard arguments from Bayesian mechanism design (see for example Ledyard and Palfrey 2002), one can show that the solution to this optimization problem is the *full provision lottery draft mechanism*. That is, the public good is always produced and a random subset of  $K$  individuals contribute, without regard to individual cost realizations. Thus, the two coordination problems (undercontribution and overcontribution) and the underprovision inefficiency are perfectly solved, but the fourth source of inefficiency, *cost inefficiency*, is ignored. The reason cost inefficiency is ignored is that the only way to sort out lower cost types from higher cost types is to sometimes fail to produce the public good. That is solving the cost inefficiency problem would require reducing the probability the public good is provided. But the cost of failing to produce the public good is extremely high. In particular, it is very high relative to the benefits of shifting the cost burden in the direction of lower cost agents. This result is summarized in the following proposition.

**Proposition 1.** *If costs are uniformly distributed on  $[0, 1]$ , then the solution to (2) is  $P(c) = 1$  and  $A(c) = \frac{K}{N}$  for all  $c \in [0, 1]$ .*

**Proof.** See Appendix A, which proves a more general result for which this is a special case.

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<sup>9</sup>The results for this case extend easily to any  $C$  such that  $0 < C \leq 1$ , as shown in the appendix.

**High cost distribution:**  $C = 1.5$

If the cost distribution admits costs with  $c_i > 1$ , as is the case when  $C = 1.5$ , then ex post individual rationality constraints play a role in characterizing the optimal communication mechanism, because it is irrational for any individual with a cost  $c_i > 1$  to contribute, since the individual benefit is only 1. Thus, the solution of (2) characterized in Proposition 1 violates ex post individual rationality when  $C > 1$ , and the analysis becomes more complicated.

We can write the ex post individual rationality constraint in the reduced form as:

$$A(c) = 0 \quad \forall c > 1$$

This constraint also implies that  $P(c)$  must be constant for all  $c > 1$ , and we will denote this expected provision for high types as  $\underline{P}$ . Denote by  $c^* = \inf\{c | A(c) = 0\} \leq 1$  and observe that  $U(c) = \underline{P} \quad \forall c \in [c^*, 1.5]$ . We know  $c^*$  exists, because  $A(c) = 0 \quad \forall c > 1$  and  $A'(c) \leq 0$ . Denote the portion of  $P$  and  $A$  defined on  $c \leq c^*$  by the functions  $\hat{P} : [0, c^*] \rightarrow [0, 1]$  and  $\hat{A} : [0, c^*] \rightarrow [0, 1]$ . With this notation, we write the optimization problem as:

$$\max_{(\hat{P}, \hat{A}, \underline{P}, c^*)} \int_0^{1.5} U(c) \frac{1}{1.5} dc \quad (3)$$

$$\text{subject to} \quad (4)$$

$$U(c) = \underline{P} \quad \forall c \in [c^*, 1.5] \quad (5)$$

$$\hat{A}(c) = -U'(c) \quad \forall c \in [0, c^*] \quad (6)$$

$$\begin{aligned} U''(c) &\geq 0 \quad \forall c \in [0, c^*] \\ \frac{K}{N} \left\{ \underline{P} [1 - F(c^*)] + \int_0^{c^*} \hat{P}(c) \frac{1}{1.5} dc \right\} &\leq \int_0^{c^*} \hat{A}(c) \frac{1}{1.5} dc \\ 0 &\leq \hat{P}(c) \leq \underline{P} \quad \forall c, \quad 0 \leq \hat{A}(c) \leq 1 \quad \forall c \in [0, c^*] \end{aligned}$$

Following arguments similar to the proof of Proposition 1, we can characterize the optimal communication mechanism as a solution to (3). The mechanism is not perfectly flat, as was the case for  $C = 1$ , but it is as flat as possible, given the binding constraint imposed by ex post individual rationality. Specifically,  $P$  and  $A$  have two flat components, which are separated at a critical cost level,  $c^*$ . Individuals with cost above  $c^*$  never contribute. Individuals with cost below  $c^*$  all contribute with the same probability.

**Proposition 2.** *If costs are uniformly distributed on  $[0, C]$  and  $C = 1.5$ ,  $K = 2$ ,  $N = 3$  then the*

solution to (2) is given by:

$$\begin{aligned}
c^* &= 0.75 \\
P(c) &= 0.75 \quad \forall c \in [0, c^*] \\
&= 0.25 \quad \forall c \in [c^*, 1.5] \\
A(c) &= \frac{2}{3} \quad \forall c \in [0, c^*] \\
&= 0 \quad \forall c \in [c^*, 1.5]
\end{aligned}$$

**Proof.** See Appendix A.

This mechanism solves the first two problems of miscoordination, because budget balance is always satisfied. On the other hand, the existence of an ex post individual rationality constraint means that the public good is not always provided, so the free rider problem is not fully solved. In fact, because  $C = 1.5$  and only two contributors are required, it is always efficient to provide the public good because the total cost of providing it is always less than 3, which is equal to the sum of public good benefits to the group. The cost inefficiency problem is also not solved in this mechanism. As with the earlier case where  $C \leq 1$ , solving the cost inefficiency problem would require reducing the probability the public good is provided. The cost of reducing the provision probability is very high relative to the benefits of shifting the cost burden to the lower cost agents.

**Binary Communication Cutpoint Equilibrium** The optimal mechanisms described above cannot be implemented with a single round of simultaneous binary communication, which is the simplest possible message space we explore in the experiment. The message space is just not rich enough to implement a jointly controlled lottery to randomly selecting exactly  $K$  contributors when more than  $K$  individuals indicate a willingness to contribute. An earlier paper (Palfrey and Rosenthal (1991)) identifies a class of cheap talk equilibrium when  $K=2$  and  $N=3$ , which we call *binary communication cutpoint equilibrium*. It remains an unproven conjecture that these equilibria are the most efficient symmetric equilibria of the communication game with one round of simultaneous binary communication. The message space is  $\{0, 1\}$  and the equilibrium is characterized by two cutpoints,  $c_c$  and  $c_3$ . In the first stage, player  $i$  reports “1” if and only if  $c_i \leq c_c$ .<sup>10</sup> Behavior in the second stage depends on how many players reported “1” in the first stage. If 0 or 1 players reported “1” then nobody contributes in the second stage. If exactly 2 players reported “1” in the first stage, then those two players

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<sup>10</sup>Thus, reporting a “1” is interpreted in equilibrium as a *conditional* promise to contribute.

contribute in the second stage and the third player does not contribute. If all 3 players reported “1” in the first stage, then those players use the cutpoint  $c_3$  as their strategy in the second stage: i.e., contribute if and only if  $c_i \leq c_3$ .<sup>11</sup>

The equilibrium is characterized by two equations, one for each cutpoint. The condition in the cheap talk stage is that a player with  $c_i = c_c$  is indifferent between reporting “1” and “0”, given the equilibrium continuation in the second period. If all other players use  $(c_c, c_3)$  the expected payoff of announcing “0” for a player with  $c_i = c_c$  equals:

$$\left(\frac{c_c}{C}\right)^2$$

and the expected payoff for announcing “1” is:

$$\left(\frac{c_c}{C}\right)^2 \left(\frac{c_3}{c_c}\right)^2 + 2 \left(\frac{c_c}{C}\right) \left(1 - \frac{c_c}{C}\right) (1 - c_c)$$

Equating these expressions and collecting terms gives:

$$(c_c)^2 = (c_3)^2 + 2 (c_c) (C - c_c) (1 - c_c) \quad (7)$$

The cutpoint in the contribution stage,  $c_3$ , is characterized by the player with  $c_i = c_3$  being indifferent between contributing and not contributing, given everyone else is using equilibrium strategies. This indifference equation is given by:

$$2 \left(\frac{c_3}{c_c}\right) \left(1 - \frac{c_3}{c_c}\right) = c_3$$

which reduces to:

$$c_3 = c_c - \frac{c_c^2}{2} \quad (8)$$

The equilibrium is obtained by simultaneously solving 7 and 8 for  $(c_c, c_3)$ . For our parameters ( $C = 1$  and  $C = 1.5$ ), the binary communication equilibrium cutpoints are summarized in Table 1.

It is interesting to note that the CCE does not eliminate all the miscoordination inefficiencies. It is possible for exactly one player to contribute, if his value is less than  $c_3$  and the other two players have values between  $c_3$  and  $c_c$ . Given the parameters of the experiment the chance this happens in

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<sup>11</sup>Obviously such equilibria can also be implemented with any richer message space, including our direct revelation message space and the text chat message space.

| $C$ | $c_c$ | $c_3$ |
|-----|-------|-------|
| 1   | 0.608 | 0.426 |
| 1.5 | 0.724 | 0.462 |

Table 1: Binary communication equilibrium cutpoints.

the CCE is very low: probability 0.05 for  $C = 1$  and probability 0.03 for  $C = 1.5$ . Similarly, it is possible for overcontribution in equilibrium, if all three players have values less than  $c_3$ . Given the parameters of the experiment the chance this happens in the CCE is also very low: probability 0.07 for  $C = 1$  and probability 0.03 for  $C = 1.5$ . Hence the welfare losses from such miscoordination is very low in expected terms, partly because the event is unlikely and partly because the value of the wasted contribution is low.

Compared to the optimal mechanism with unlimited communication, the welfare losses in the communication equilibrium are still very large because of the high probability of non-provision. The probability of non-provision is approximately 0.39 for  $C = 1$ , which is nearly as great as the probability of non-provision in the symmetric Bayes Nash equilibrium (0.50), and far worse than the optimal mechanism, which always produces the public good. For  $C = 1.5$  the probability of non-provision is 0.56, which is much less than the probability of non-provision in the symmetric Bayes Nash equilibrium, which is 0.84. Thus the potential gains from binary communication are greater for  $C = 1.5$  than for  $C = 1$ .

## 4 Experimental Design and Hypotheses

The experimental design, procedures and treatments are discussed in Section 4.1. Section 4.2 lists the hypotheses that are formally tested.

### 4.1 Design, Procedures and Treatments

The experiments were conducted at the California Social Science Experimental Laboratory (CASSEL), University of California, Los Angeles (UCLA) using the Multistage software package. Participants were recruited from a pool of volunteer subjects, maintained by CASSEL. A total of sixteen sessions were run, using 183 subjects. Each session consisted of 9-15 participants and no subject participated in more than one session<sup>12</sup>. Upon arrival, instructions were read aloud. Subjects interacted anonymously with each other through computer terminals. Sessions lasted from 30 to 50 minutes and participants earned on average US\$18.47 in addition to a show-up fee of US\$5<sup>13</sup>.

<sup>12</sup>Eleven sessions had 12 subjects, four sessions had 9 subjects and one session had 15.

<sup>13</sup>Payoffs ranged from US\$11 to US\$25.50 with a standard deviation of US\$3.18.

In all the experiments, we set  $K = 2$  and  $N = 3$ . Each individual  $c_i$  is an independent random draw from a uniform distribution on  $[0, C]$ , and the experimental design allows for two values of  $C$  (1 and 1.5) corresponding to the two cases analyzed in the theoretical section of the paper.  $C = 1$  means that it is common knowledge that everyone has costs lower than the public benefit and hence, no one has a dominated contribution strategy. However, in the situation with  $C = 1.5$ , individuals have a strictly dominant strategy not to contribute whenever  $c_i > 1$ , implying the problem of ex post individual rationality in the communication equilibria.

The communication structure was varied in each of the two parametric configurations,  $C = 1$  and  $C = 1.5$ . We used four communication treatments: “no communication”, “binary communication”, “direct revelation”, and “unrestricted text chat”, resulting in a  $2 \times 4$  design. We ran two sessions for each of these treatments, thus a total of 16 sessions. The details of the experimental protocols are briefly discussed below<sup>14</sup>. Each session consisted of 20 rounds. After a round was over, participants were randomly rematched into new three person groups and everyone was independently and randomly assigned new costs. The random rematching was done to limit the reputation and super-game effects which might occur with repeated play.

## No Communication

Contribution costs were implemented as opportunity costs. In each round, each subject was allocated a single indivisible “token”, which had a private value that was referred to as a “token value”. Subjects were informed that token values in integer increments between 1 to  $100C$  points are independently drawn with replacement from identical uniform distributions and randomly assigned to subjects. Each subject was informed of her token value but knew only the probability distribution of other subjects’ token values. Each subject was then asked to enter a decision to spend or keep their token. If at least two of the three subjects spent their token, then each subject received 100 points if she had chosen to spend her token, while the payoff was 100 points *plus her token value* if she had chosen to keep her token. If a subject chose to spend but none of her other group members spent their tokens then that subject earned 0 points in the round. If a subject chose to not to spend and fewer than two other group members spent their tokens then that subject earned her token value in the round.<sup>15</sup>

<sup>14</sup>For details, please see the instructions provided in Appendix B.

<sup>15</sup>Due to an error in the computer program, no subject received a token value equal to 100 in the  $C = 1$  treatment and 150 in the  $C = 1.5$  treatment; the actual distribution was uniform from 1 to 99 or 149, respectively.



## **Binary Communication (“Binary”)**

Each round had two stages: a communication stage and a contribution stage. In the communication stage, subjects chose one of the two messages: “I intend to spend my token”; “I intend to keep my token”. They were advised that these messages were not binding, and they could make either contribution decision regardless of which message they sent in the communication round. After these binary messages were sent, each person was told how many members in their group sent each message, and was reminded which message he or she had sent. This was directly followed by the contribution stage, where individuals made binding contribution decisions.

## **Direct Revelation (“Token”)**

Each round again had a communication stage and a contribution stage. In the communication stage, subjects had 20 seconds to send a message to the other members of her group. They were told that this message can only be an integer between 1 and  $100C$  and each member was allowed to send only one such message. Thus, the message space in this treatment corresponds to the direct mechanism and is much larger than the “binary communication” sessions. Each subject observed the messages sent by her group members. Each subject was also told that in the event she did not send any message, the other members of her group would see a “ ? ” against her subject id at the end of the 20 seconds. After the communication stage was over, individuals made contribution decisions. We called this treatment “token” because subjects had the opportunity to reveal their true token values. If token values were revealed truthfully, there would be the opportunity for perfect coordination in the  $C = 1$  condition, with the two individuals with the lowest token values contributing. In principle, the same could occur in the  $C = 1.5$  condition, provided at least two individuals had token values no greater than 100.

## **Unrestricted Broadcast Text Chat (“Chat”)**

This treatment consisted of the same number of rounds as in the other ones and had the same two stages, with the only difference being in the structure of the communication stage. Prior to the contribution stage, every group had a discussion period which lasted 60 seconds, during which subjects could send messages to the other members of the group. Individuals were told that the messages had to conform to certain rules, including that they must be relevant to the experiment and subjects should not send messages intended to reveal their identity. Thus, the message space under this treatment is ‘anonymous, unrestricted and unstructured text messages’ and is much larger than the finite message space under the “token revelation” sessions. Importantly, this treatment gave subjects the opportunity to employ natural language.

## 4.2 Hypotheses

We test several hypotheses regarding (a) the effect of communication on efficiency, (b) comparison across communication treatments differing in the richness of message space, and (c) differences across  $C = 1$  and  $C = 1.5$  sessions.

The effect of communication on efficiency is broken down into four separate hypotheses with respect to the total earnings generated, the likelihood of public good provision, the number of contributors and the costs of contributors. First, as there exist equilibria under communication that have higher payoffs for players than in the Bayesian Nash equilibrium without communication, one can conjecture that the earnings would indeed be higher if communication is allowed. For similar reasons, we expect the public good to be provided more often if there is pre-play communication than without any communication communication. These give rise to our first two hypotheses:

*Hypothesis 1 (Earnings Hypothesis). Total earnings are higher with communication than without communication.*

*Hypothesis 2 (Provision Hypothesis). The likelihood of public good provision is greater in the communication sessions than in the non-communication sessions.*

The ex ante efficient solution is for just two individuals to contribute their token, and for the contributors to have the two lowest costs while the free rider has the highest cost (ignoring ties). Without communication, it is impossible for players to know who has relatively high valuations and who has relatively low ones. Thus the “efficient” outcome can occur only by chance. However, with sufficient communication, it is at least feasible to coordinate decisions in a way that produces this desired outcome. Thus, we can expect to have fewer wasteful contributions, that is, fewer incidences of one or three individuals contributing in the case with communication. In other words, communication leads to lower production inefficiency by lowering both over and under-contributions. Also, conditional on the public good being provided, we should have a higher percentage of the subjects with the two lowest costs contributing when communication is allowed. Thus, communication can help in two ways: one by reducing coordination failures (such that only two contribute) and other by making the two lowest costs contributing. Hence, we have the following hypotheses:

*Hypothesis 3a (Under-contribution Hypothesis). The incidence of exactly one person in a group contributing is lower in the communication sessions than in the non-communication sessions.*

*Hypothesis 3b (Over-contribution Hypothesis). The incidence of all members in a group contributing is lower in the communication sessions than in the non-communication sessions.*

*Hypothesis 4 (Efficiency Hypothesis). Conditional on the public good being provided, the incidence of individuals with the lower two costs contributing is higher with communication than under no*

communication.

We study three different forms of communication. While the binary sessions use an exchange of binary messages, the token sessions have a much larger although finite message space, including a null message. The ‘text chat’, while anonymous, uses natural language in continuous time. Hence, we have a progression in the treatments in terms of the richness of the message space implemented. One would expect that it would be easier to implement efficient outcomes as the message space becomes richer and this leads to a hypothesis that there will be a monotonic relation between efficiency and richness of the message space:

*Hypothesis 5 (Monotone Hypothesis). Efficiency increases with the richness of the message space. It is highest in the chat treatment, followed by the token treatment, followed by the binary treatment, and lowest in the no communication treatment.*

The final hypothesis compares the provision of public good across the two different  $C$  sessions. When it is common knowledge that every member’s cost is less than the benefit from the public good, 100% provision of public good is possible. However, in the  $C = 1.5$  case, it is no longer possible to provide the public good all the time assuming subjects do not use dominated strategies. Indeed the probability that the good isn’t provided equals  $\frac{7}{27}$ , when at least two of the subjects have costs greater than 100. This gives us the following hypothesis:

*Hypothesis 6 ( $C$  Hypothesis). For each communication protocol, the probability of public good provision is greater in the  $C = 1$  sessions than in the  $C = 1.5$  sessions.*

## 5 Results

Here we first present the results from testing the specific hypotheses that we discussed earlier. Subsection 5.2 compares the performance of the data in all treatments to the various theoretical benchmarks. The final subsection briefly discusses the behavior in the communication stages of the different treatments.

### 5.1 Group Outcomes and Test of Hypotheses

The first hypothesis involves a comparison between the average earnings without communication to the average earnings with the three communication treatments. Table 2 documents the average group earnings net of token values in rounds 11-20 for the four treatments, in both  $C$  sessions.<sup>16</sup> In the  $C = 1$  sessions, average net earnings are higher with communication in both the “token” and the

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<sup>16</sup>Unless otherwise noted, throughout the results section, we consider only the data from rounds 11-20 for performing the statistical analyses. Tables reporting the results for the first 10 round and for all 20 rounds combined are in Appendix C.

“chat” treatments, but the difference is significant only for the “chat” treatment. The other two communication treatments yield similar earnings as those under ‘no communication’. In the  $C = 1.5$  sessions, ‘chat’ results in higher earnings only in the second half of the experiment. We use the net earnings as opposed to gross earnings to reduce the ‘randomness’ present due to the realization of the drawn token values.

|                | No Comm. | Binary Comm.                | Token Revelation | Chat     |
|----------------|----------|-----------------------------|------------------|----------|
|                |          | <u><math>C = 1</math></u>   |                  |          |
| Provision rate | 0.43     | 0.41                        | 0.50             | 0.98***  |
| Group earnings | 88.0     | 80.2                        | 101.5            | 221.1*** |
| Observations   | 70       | 80                          | 80               | 60       |
|                |          | <u><math>C = 1.5</math></u> |                  |          |
| Provision rate | 0.28     | 0.38                        | 0.25             | 0.43**   |
| Group Earnings | 39.6     | 58.7                        | 42.1             | 83.4***  |
| Observations   | 80       | 80                          | 80               | 80       |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%.

Table 2: Average group earnings net of token values and frequency of public good provision. Significance levels are for differences between the communication treatment and ‘No Communication’.

Taking each group as an independent observation, one-tailed Mann-Whitney tests show that there is no significant difference in the net group earnings between ‘binary communication’ and ‘no communication’ treatments and between ‘token revelation’ and ‘no communication’ treatments. However, the differences are statistically significant at the 1% level only between ‘no communication’ and ‘chat’ implying that only when subjects are provided with unstructured communication in the form of text chat, they end up with higher earnings. This is true for both  $C$  sessions. The above discussion leads us to support *Earnings Hypothesis* and conclude the following:

*Result 1. Total earnings are significantly higher with communication only in the chat condition (H1).*

Table 2 also collects the probabilities of the public good provision for rounds 11-20 in each of the four treatments. An immediate finding is that in line with the previous result, not all forms of communication increase the likelihood of the good being provided. Clearly, ‘binary communication’ and ‘token revelation’ sessions result in either similar or lower public good provision when compared to ‘no communication’ sessions, considering the two  $C$  sessions. It is only in the ‘chat’ treatment that the provision of good is higher in both  $C = 1$  and  $C = 1.5$  sessions. A difference in proportions z-test for each of the binary comparisons of the ‘communication’ sessions with the ‘no communication’ sessions shows that there is significant difference between ‘unrestricted chat’ and ‘no communication’

in both  $C$  sessions (at 5% level)<sup>17</sup>. Supporting *Provision Hypothesis*, we have the following:

*Result 2. The likelihood of public good provision is significantly greater with communication only in the chat condition, for both cost treatments (H2).*

Next, we turn to the following question: Does communication help in reducing production inefficiency in the form of wasteful contributions? While the frequency with which exactly one group member contributes is always lower with communication, the difference is significant only for the ‘chat’ treatment (see Table 3). With respect to overcontribution where all three individuals in a group contribute, communication helps in all communication sessions but only for  $C = 1$  sessions. So, communication helps in reducing production inefficiency through both the lowering of undercontribution as well as overcontribution. The percentage of over-contribution is already low without any communication. Thus, supporting *Under-contribution Hypothesis* and *Over-contribution Hypothesis*, we have the following results:

*Result 3a. For both cost treatments, the incidence of exactly one person in a group contributing is lower in all communication treatments. It is significantly lower in the chat condition (support for H3a).*

*Result 3b. For both cost treatments, the incidence of all three persons in a group contributing is lower in all communication treatments. It is significantly lower only in the  $C = 1$  chat condition (support for H3b).*

| Contributors                | No Comm. | Binary Comm. | Token Revelation | Chat    |
|-----------------------------|----------|--------------|------------------|---------|
| <u><math>C = 1</math></u>   |          |              |                  |         |
| 0                           | 11.4     | 17.4         | 9.9              | 0.0***  |
| 1                           | 45.7     | 41.3         | 40.0             | 1.7***  |
| 2                           | 28.6     | 35.0         | 38.8             | 96.6*** |
| 3                           | 14.3     | 6.3*         | 11.3*            | 1.7***  |
| nobs                        | 70       | 80           | 80               | 60      |
| <u><math>C = 1.5</math></u> |          |              |                  |         |
| 0                           | 24.9     | 23.7         | 35.0             | 27.5    |
| 1                           | 47.5     | 38.8         | 40.0             | 30.0**  |
| 2                           | 20.0     | 35.0         | 17.5             | 37.5    |
| 3                           | 7.6      | 2.5          | 7.5              | 5.0     |
| nobs                        | 80       | 80           | 80               | 80      |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. These significance levels are for difference in proportions z-tests across the communication treatment and ‘No Communication’.

Table 3: Frequency distribution of number of contributors in percentages, communication treatment.

<sup>17</sup>These are results from one-tailed tests of difference in two independent proportions. For the  $C = 1$  situation, the data numbers do not satisfy the criteria:  $n(1 - p) > 5$ , where  $n$  is the number of observations and  $p$  is the proportion. But its easy to infer that the proportion is almost 1 under ‘unrestricted chat’ and hence there would be a significant difference when compared with the ‘no communication’ session.

Results 3a and 3b clearly illustrate one of the most fundamental roles of communication in these threshold public goods games: *communication improves coordination*. When either two or zero members of the group contribute, there is no miscoordination. There is free riding in the case of zero contribution, but no wasted contributions. With exactly two contributors, there may be a small inefficiency due to the private information about costs if the two contributors do not have the two lowest costs, but there is no miscoordination and no wasted contributions. In contrast, when one or three members of the group contribute, inefficiencies result purely from miscoordination, resulting in deadweight loss.

Finally, to combine results 3a and 3b, we compare the frequency of coordinated outcomes (0 or 2 contributors) and the frequency of coordination failures (1 or 3 contributors) across the four communication treatments in the two cost treatments. This comparison is shown in Table 4. Communication clearly leads to meaningful increases in coordination in all cases. The percentage increases in coordinated outcomes relative to no communication range from a 17% increase in the case of ‘token revelation’ with  $C = 1.5$  to a 141% increase in the case of ‘chat’ with  $C = 1$ . Five out of six increases relative to no communication are statistically significant.

| C     | No Comm. | Binary Comm. | Token Revelation | Chat    |
|-------|----------|--------------|------------------|---------|
| C=1   | 40.0     | 52.4***      | 48.7**           | 96.6*** |
| C=1.5 | 44.9     | 58.7***      | 52.5             | 65.0*** |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. These significance levels are for difference in proportions z-tests across the communication treatment and ‘No Communication’.

Table 4: Frequency of coordinated outcomes (0 or 2 contributors).

The most efficient outcome occurs when exactly two people in a group contribute and those two have the lower two costs. Conditional on the good being provided, Table 5 documents the percentage of times the subjects with the lower two costs contribute across the four treatments and for each  $C$  session. The numbers are quite high, even without communication. With  $C = 1$ , full efficiency would require 100% of the time the two lowest costs contribute. Obtaining 86.4% in the last 10 rounds of ‘chat’ is very much higher than pure chance.

The incidence of subjects with the two lowest costs in a group contributing is higher in all communication treatments compared to no communication, with the single exception of the  $C = 1.5$  ‘token’ communication treatment. However, this difference is only significant in the ‘chat’ treatment with  $C = 1$ . Thus, similar to Results 1 and 2, we conclude that only one form of communication leads to a statistically significant improvement in cost efficiency:

*Result 4. Conditional on the public good being provided, the incidence of individuals with the lower two costs contributing is significantly higher with communication than no communication only in the chat treatment (H4).*

| C         | No Comm.  | Binary Comm. | Token Revelation | Unrestricted Chat |
|-----------|-----------|--------------|------------------|-------------------|
| $C = 1.0$ | 56.7 (30) | 57.6 (33)    | 65.0 (40)        | 86.4*** (59)      |
| $C = 1.5$ | 68.2 (22) | 70.0 (30)    | 55.0 (20)        | 79.4 (34)         |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. These significance levels are for difference in proportions z-tests across the communication treatment and ‘No Communication’.

Table 5: Percentage of times exactly two lowest costs contribute, conditional on provision. Number of observations where the public good is provided in parentheses.

Summarizing the above results, we find that the structure of communication is crucial in determining whether there are significant gains over the situation where communication is not possible. The simultaneous exchange of binary messages aimed at disclosing intentions as well as the one-time broadcasting of a numerical message lead to some improvements, particularly with respect to a reduction in the frequency of miscoordination, but these gains are for the most part not large enough in magnitude to significantly improve average earnings and the probability of public good provision. With these coarser communication structures, groups also are generally not successful in bringing the members with the lowest two token values to contribute. Only when a rich form of continuous time communication with a “common language” is possible, are there significant gains in efficiency. While these gains are enormous (approaching the first best outcomes) in the  $C = 1$  treatment where it is common knowledge that everyone has a cost that is less than the benefit from the public good, these gains are harder to achieve in the  $C = 1.5$  treatment, where some individuals can have private costs that exceed the benefit.

Given results 1-4, it is now straightforward to test Hypothesis 5. Whether it is measured with respect to the average group earnings, likelihood of public good provision, incidence of wasteful contributions, or the subjects with lower two costs contributing, there is no strict progression in efficiency as we move from no communication to binary to a larger numerical message space to finally the “infinite” communication structure. The relation between efficiency and the richness of message space is *weakly* monotonic, but not strictly monotonic as hypothesized.

*Result 5. Efficiency does not increase monotonically in the richness of the message space of the communication stage (reject H5). It is significantly higher only for the chat treatment.*

The final hypothesis compares the likelihood of providing the public good in  $C = 1$  and  $C = 1.5$  sessions. There were 489 instances out of 1918 total observations (that is 25.5% of the cases) when

at least two of the subjects in a group had costs higher than 100 in the  $C = 1.5$  sessions. The public good was provided in 6 out of 114 observations in the ‘binary communication’ treatment. In the other treatments, the good was never provided when there was only one person in a group having a cost less than 100 (out of a total of 375 such instances). These numbers strongly support Hypothesis 6. As can be seen from Table 2, public good provision is much higher in the  $C = 1$  sessions than in the corresponding  $C = 1.5$  sessions. The differences are significant at the 1% level for ‘direct revelation’ communication and ‘chat’, and at the 5% level for the ‘no communication’ sessions.

*Result 6. Keeping the communication protocol fixed, the probability of public good provision is greater in the  $C = 1$  sessions than in the  $C = 1.5$  sessions (support for H6).*

## 5.2 The Quantitative Effects of Communication on Normalized Efficiency

We now turn to the analysis of how the outcomes compare with the theoretical bounds discussed in Section 3 as well as the first-best outcome. Figure 1 displays *normalized efficiency*, defined as group earnings net of token values as a percentage of first best group earnings net of token values. The graph displays the data (with 95 percent confidence intervals) and also the normalized efficiency in the optimal mechanisms characterized in Section 3, based on the actual cost draws in the data. The normalized efficiency of the Bayesian Nash equilibrium for each treatment are marked on the graph with horizontal lines, also based on the actual cost draws. The left panel is for the  $C = 1$  data and the right panel is for the  $C = 1.5$  data.

The normalized efficiency results can be summarized as follows. First, in all cases, groups do much better than if nobody contributed. That is, normalized efficiency is significantly greater than zero in all eight treatments. Second, with the exception of the chat communication treatments<sup>18</sup>, normalized efficiency is significantly lower than in the optimal mechanism. Third, in all of the  $C = 1$  treatments efficiency is lower than in the Bayes-Nash equilibrium. Fourth, in contrast to the third finding, for the  $C = 1.5$  data, normalized efficiencies are always higher than the Bayes Nash equilibrium.

## 5.3 Individual Behavior: Messaging and Contribution Strategies

In this section, we take a deeper look at the individual choice data as a function of individual token values. We describe several findings about the strategies used by subjects in the communication stage, and about how the messages in the communication stage affected contribution decisions. These are presented below, separately for each of the communication structures. We use data from the last 10

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<sup>18</sup>Interestingly, in the ‘chat’ with  $C = 1$ , groups do even slightly better than the best IC mechanism and are close to the first-best outcome.



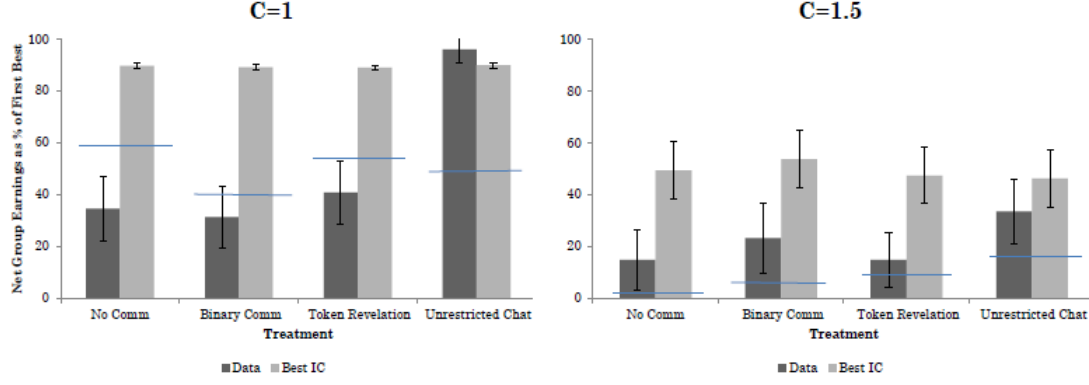


Figure 1: Normalized efficiency net of token values by treatments (rounds 11-20). Also shown are the 95% confidence intervals. The horizontal line denotes the Bayes-Nash equilibrium normalized efficiency for each treatment.

rounds in this section.<sup>19</sup>

## Binary Communication

We start by analyzing the decision of whether to send an intent to spend message or an intent to keep message, and to compare this with the theoretical communication equilibrium given in Table 1. Theoretically, an intent to spend message should be observed 61% of the time in the  $C = 1$  treatment and 72% of the time in the  $C = 1.5$  treatment (conditional on token values less than 100). The observed values were 66% and 81%, respectively. Thus, intent to spend messages were observed more frequently in the  $C = 1.5$  treatment, but in both cases such messages were observed more frequently than in the communication equilibrium given in Table 1. In both treatments, the frequency of intent to spend messages was decreasing in token value, as shown in the probit regression results displayed in Table 6.

Next, we look at the effect of the binary messages on the spending decision of a subject. Table 7 shows the effect of own binary message and the profile of binary messages of the other two members of the group on own contribution decision. Because the messages are sent anonymously, the decision only depends on the number of other “intend to spend” messages in the group. The entries in the table are the contribution rates of the subject in each category. Based on the theoretical communication equilibrium in Table 1, when  $C = 1$ , an individual is expected to contribute 74% of the time after she said that she intended to contribute in the message stage, while this number is 65% for  $C = 1.5$

<sup>19</sup>For  $C = 1.5$ , unless otherwise noted the observations with token values higher than 99 are dropped in this section because these individuals have a dominant strategy not to contribute, and almost never do. Across all communication treatments, in 632 cases where an individual’s token value was greater than 100, there were only 11 observations of contribution.

|                        | $C = 1$           | $C = 1.5$        |
|------------------------|-------------------|------------------|
| Tokenvalue             | -0.005*** (0.002) | -0.004** (0.002) |
| Constant               | 1.11*** (0.32)    | 1.61*** (0.40)   |
| Number of observations | 240               | 159              |
| Pseudo R <sup>2</sup>  | 0.061             | 0.056            |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%

Table 6: Message behavior in the ‘Binary Communication’ treatment: Marginal effects from a probit regression with “message” as the dependent variable. Standard errors, clustered at the subject level, are in parentheses.

| Message sent by me  | Number of others saying “I intend to spend” |           |           |
|---------------------|---|-----------|-----------|
|                     | 0   | 1         | 2         |
|                     |   | $C = 1$   |           |
| “I intend to spend” | 0.41 (22)                                   | 0.60 (48) | 0.56 (90) |
| “I intend to keep”  | 0.25 (12)                                   | 0.23 (44) | 0.13 (24) |
|                     |   | $C = 1.5$ |           |
| “I intend to spend” | 0.38 (21)                                   | 0.82 (49) | 0.62 (58) |
| “I intend to keep”  | 0.00 (1)                                    | 0.16 (19) | 0.27 (11) |

Table 7: Fraction of times spent as a function of binary message profile. Total observations in parentheses.

sessions. When  $C$  was 1, an individual contributed 55% of the time after she said that she intended to contribute in the message stage, while this number was 66% for  $C = 1.5$  sessions. In contrast, individuals are expected to never contribute when they send an intent to keep message. Only 20% of the time did a person contribute after sending an intent to keep message in the  $C = 1$  sessions, while the comparable percentage for  $C = 1.5$  groups was 19%.

The main departure from the theoretical conditional contribution rates, is that in theory, if you and exactly one other individual sends a spend message then your predicted contribution rate is 100%. This is not what we observe in the data, especially in the  $C = 1$  data. In the  $C = 1$  sessions, out of 48 observations with “I intend to spend my token” with exactly one other member sending this message, only 29 contribute. When no other member sent that message, only 9 of 22 contributed, but in the communication equilibrium none of these should be contributing. When both other members also reported that they intended to spend, 49 out of 90 contributed (54%), while in theory this is predicted to be somewhat greater (70%). For  $C = 1.5$  sessions, only 38% of subjects who reported an intent to spend carry out that intent when nobody else in the group sent the spend message. This contrasts with much higher rates when at least one other member says they intend to spend: 82% with one other and 62% with two others.

While these conditional contribution rates are different from the theoretical ones implied by Table

1, they reveal some interesting patterns in the contribution rates of individual who report an intent to spend. First, individuals are always more likely than not to carry out a reported intent to spend than not *only if at least one other member of the group also reports an intent to spend*. Second, this effect is strongest when exactly one other member reports an intent to spend. These patterns provide some additional insight into the earlier finding that binary communication partially alleviates the coordination failure that occurs when exactly one individual contribute (see Tables 3 and 4).

Individuals who report an intent to keep are always much more likely to keep than spend, regardless of how many other members of the group report an intent to spend. In cases where an individual reports “intend to keep”, the effect of other messages on contribution decisions is small, and with no clear pattern. In the  $C = 1$  treatment, the probability of contributing declines very slightly with the number of other members who intend to spend, but it goes the other direction in the  $C = 1.5$  treatment.

To evaluate the statistical significance of these effects, Table 8 shows the results of a probit regression with contribution decision as the binary dependent variable, as well as whether the subject sent the message “I intend to spend my token” ( $m_i = 1$ ) or “I intend to keep my token” ( $m_i = 0$ ). We denote the number of *other* members in a group saying “I intend to spend” in the message stage as  $M_{-i}$ . The independent variables are as follows: own token value ( $tokenvalue_i$ ),  $\mathbb{1}\{M_{-i} = 1\}$ : a binary variable indicating whether exactly one of the other two members sent the message “I intend to spend” and  $\mathbb{1}\{M_{-i} = 2\}$ : a binary variable indicating whether both the other members sent the message “I intend to spend”.

The regression results in Table 8 confirm the effects identified in Table 7. Given that an individual has sent “I intend to spend” message, she is more likely to contribute if there was at least one other member who expressed the willingness to spend in the message stage. This effect is significant in three of four cases, and the effect is strongest if there was exactly one other person in the group who reported an intent to spend. In contrast, none of the  $M_{-i}$  coefficients are significant in case  $m_i = 0$ .

## Token Revelation

In the ‘token revelation’ treatment, individuals rarely chose the option of sending an empty message (7.5% of the time in  $C = 1$  groups and 14% of the time when  $C$  was 1.5). In  $C = 1$  groups, 49% of the reports were truthful and 41% of the reports were lower than the true token values, while individuals over-reported their token values only 10% of the time. A similar pattern was observed in the  $C = 1.5$  groups, where 44% of the reports were truthful, 38% were under-reported and 18% over-reported. Again, from the prevalence of under-reporting of token values it seems that individuals were trying

|                            | $m_i = 0$         | $m_i = 1$        | $m_i = 0$      | $m_i = 1$         |
|----------------------------|-------------------|------------------|----------------|-------------------|
|                            | $C = 1$           | $C = 1$          | $C = 1.5$      | $C = 1.5$         |
| $tokenvalue_i$             | -0.005*** (0.002) | -0.01*** (0.003) | -0.005 (0.003) | -0.005*** (0.002) |
| $\mathbb{1}\{M_{-i} = 1\}$ | -0.01 (0.14)      | 0.26* (0.15)     | -0.037 (0.13)  | 0.23** (0.1)      |
| $\mathbb{1}\{M_{-i} = 2\}$ | -0.16 (0.11)      | 0.27* (0.16)     | 0.41 (0.3)     | 0.06 (0.1)        |
| Constant                   | 0.52 (0.66)       | 1.02*** (0.37)   | 0.23 (0.94)    | 0.82** (0.34)     |
| Number of observations     | 80                | 160              | 31             | 128               |
| Pseudo R <sup>2</sup>      | 0.158             | 0.262            | 0.238          | 0.108             |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%

Table 8: Decision in the Binary Communication treatment: Marginal effects from probit regression with “contribution decision” as the dependent variable, evaluated at the means of the independent variables. Standard errors, clustered at the subject level, are in parentheses.

to signal their group members that they can expect a contribution, perhaps believing that their own low report would induce others to contribute. In the  $C = 1.5$  sessions, individuals with token values greater than 100 under-reported 55% of the time while they reported truthfully around 35% of the time. This behavior is more difficult to rationalize, but again it’s possible that subjects again thought this would induce greater contribution by others. Out of 71 such instances when their token values were higher than 100, 36 times they sent a message less than 100. That appears to be one of the primary reasons of why efficiency is so low with direct mechanism communication when  $C$  is 1.5. In contrast, out of 135 cases when the token value was less than 100, only 16% of the time individuals sent a message greater than 100. They were truthful 48% of the time and over-reported 23% of the time.

Table 9 reports the results of a linear regression of the reported token value as a function of an individual’s true token value<sup>20</sup>. As is evident, there is a significant positive relationship between token values and reported token values. We ran a probit regression to analyze how the messages exchanged in the ‘token revelation’ round affect the contribution decision of a subject<sup>21</sup>. The dependent variable is the contribution decision which is binary: 1 if the individual contributes and 0 otherwise. The exogenous variables are (i) an individual’s own  $tokenvalue_i$ , and (ii)  $\mathbb{1}\{tokenvalue_i > \max\{m_j\}_{j \neq i}\}$ : a binary variable indicating whether or not the subject’s token value is greater than the messages sent by other two members. We expect the sign of the coefficient on the variable  $\mathbb{1}\{tokenvalue_i > \max\{m_j\}_{j \neq i}\}$  to be negative, meaning that an individual is less likely to contribute if her  $tokenvalue$  is higher than the other two members’ reports. The coefficient is negative only for  $C = 1$  groups, and significant only at the 10% level (see Table 10). These findings, coupled with the fact that there is widespread mis-reporting of token values are suggestive of why groups are unable to

<sup>20</sup>The few observations where a subject did not send a message are dropped from the regression.

<sup>21</sup>The observations where at least one member of a group did not send any message are dropped.

use the ‘token revelation’ stage for much gain in efficiency.

|                        | $C = 1$         | $C = 1.5$       |
|------------------------|-----------------|-----------------|
| Tokenvalue             | 0.38** (0.07)   | 0.82** (0.12)   |
| Constant               | 17.18*** (3.79) | 13.10*** (6.75) |
| Number of observations | 222             | 135             |
| R <sup>2</sup>         | 0.104           | 0.110           |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%

Table 9: Message behavior in the direct mechanism communication treatment: Linear regression with reported token value as the dependent variable. Standard errors, clustered at the subject level, are in parentheses.

|   | $C = 1$           | $C = 1.5$         |
|---|-------------------|-------------------|
| Tokenvalue  | -0.014*** (0.002) | -0.013*** (0.003) |
| $\mathbb{1}\{tokenvalue_i > \max\{m_j\}_{j \neq i}\}$ | -0.183* (0.107)   | 0.029 (0.131)     |
| Constant  | 1.90*** (0.21)    | 1.71*** (0.32)    |
| Number of observations                                | 222               | 135               |
| Pseudo R <sup>2</sup>                                 | 0.32              | 0.31              |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%

Table 10: Decision in the direct mechanism communication treatment: Marginal effects from probit regression with contribution decision as the dependent variable, evaluated at the mean of independent variables. Standard errors, clustered at the subject level, are in parentheses.

## Chat

We investigate the question of how pre-play communication in the form of unrestricted text chat helps subjects achieve higher payoffs. Table 11 gives the details of how many times a group reached some form of an agreement about the possible profile of actions to be taken by the members in the group in the contribution stage.<sup>22</sup>

Groups reached an agreement nearly 88% of the time in  $C = 1$  treatment, and these agreements were carried out 94% of the time (99 out of 105). The ability of groups to reach agreements and carry them out was not nearly as successful in the  $C = 1.5$  treatment. The percentage of groups who reached an agreement was only 58%, which is significantly lower. Moreover, of those groups that reached agreement, only 38% (35 out of 93) carried out the agreement. The qualitative nature of the agreements was also different across the cost treatments. In the  $C = 1.5$  treatment fewer than half the agreements (38 out of 93) were for exactly two of the group members to spend, the efficient outcome, and only 20 of these groups carried out that efficient agreement. Just as many groups agreed to the

<sup>22</sup>Here we present data for all rounds, because there are interesting comparisons between early and late rounds.

non-credible agreement for all three to contribute. Not surprisingly these agreements were carried out only 8% of the time (3 out of 38). The agreements in the  $C = 1$  treatment were much different. 98 out of 105 agreements were for exactly two contributors and this was carried out 94% of the time (92 out of 98). There were five agreements for all three to spend and, perhaps surprisingly, all of these agreements were carried out. The difference between the  $C = 1.5$  and  $C = 1$  treatments is even starker after subjects have gained experience. In rounds 11-20 of the  $C = 1$  treatment agreements were nearly always reached (56/60) and moreover *all 56 agreements* were for exactly two contributors, and only once did the agreement failed to be carried out. In rounds 11-20 of the  $C = 1.5$  groups, there was a slight increase in the number of agreements for exactly two contributors (from 12/80 to 26/80), but these agreements were carried out less than half the time, which is the same rate as in the early rounds. Otherwise there was no notable change with experience in group agreements for the  $C = 1.5$  groups.

| Rounds                      | Agreements | Agreed  |      |         |        | Number | Spending |
|-----------------------------|------------|---------|------|---------|--------|--------|----------|
| <u><math>C = 1</math></u>   |            | 0       | 1    | 2       | 3      |        |          |
| 1-10                        | 49 (60)    | 2 (2)   | 0(0) | 37 (42) | 5 (5)  |        |          |
| 11-20                       | 56 (60)    | 0 (0)   | 0(0) | 55 (56) | 0 (0)  |        |          |
| All rounds                  | 105 (120)  | 2 (2)   | 0(0) | 92 (98) | 5 (5)  |        |          |
| <u><math>C = 1.5</math></u> |            |         |      |         |        |        |          |
| 1-10                        | 39 (80)    | 4 (5)   | 1(3) | 6 (12)  | 0 (19) |        |          |
| 11-20                       | 54 (80)    | 6 (6)   | 1(3) | 14 (26) | 3 (19) |        |          |
| All rounds                  | 93 (160)   | 10 (11) | 2(6) | 20 (38) | 3 (38) |        |          |

Table 11: Agreement on an action profile in the communication stage: the first column gives the frequency of times a group reaches an agreement. Columns 2-5 gives the number of times the group members carry out the agreed action profile in the contribution stage (number of observations in parentheses).

A group agrees to either of the three action profiles: (i) all members will spend their token, (ii) two of the members will spend their tokens, or (iii) everybody in the group will keep their tokens. Table 11 shows that when a group decides that all members should keep their tokens, they carry out this agreement quite well, almost 100% of the time, but when everyone in a group decides to spend their tokens, then only in a few number of cases they carry out this action. Of course, this is expected as a member might think that she could just keep her token while the other two are going to spend. This thinking actually leads to none or only one person contributing.

To summarize, the most striking feature of the chat communication is that when a group reaches an agreement in the  $C = 1$  sessions in rounds 11-20, 100% of the time they decide that exactly 2 members will spend their tokens and they nearly always carry out this agreed upon profile of actions. This explains the extremely high efficiency levels reached in rounds 11-20 in  $C = 1$  sessions. This degree of success is not even close to being achieved by the  $C = 1.5$  groups, although the frequency of groups agreeing to profiles where exactly two members spend their tokens is slightly higher in rounds 11-20, which accounts for the slightly higher efficiency in rounds 11-20 than the first ten rounds of play in the  $C = 1.5$  groups.<sup>23</sup>

### Content Analysis of Chat Messages

Finally, we provide a content analysis of the discussion in the communication round of the chat sessions to give a more complete picture of how the chat communication facilitated cooperation and coordination. Each message sent by a subject was coded into one of the nine mutually exclusive categories, as enumerated in Table 12. The table also contains some verbatim examples of sentences/messages that fall under each category that were used in our experiments. The instructions did not indicate that the chat was to be in English, and subjects communicated in a language that was closer to SMS texts than to ordinary English. Table 13 gives the percentage of all messages that fall in these nine categories in all four sessions of the ‘chat’ treatment. While “confirmation”/“strategy suggestion”/“revelation of own token value” were used a lot in the  $C = 1$  sessions, there was a predominance of informative discussions and messages related to revealing the intent to spend in the  $C = 1.5$  sessions. Messages falling in categories “strategy suggestion” and “confirmation” were used less in sessions with  $C = 1.5$  than in the  $C = 1$  sessions. Table 13 also shows that individuals used conditional statements or ambiguous messages very rarely in all of the sessions. Lastly, there was also no notable difference in the messages sent over time.

Thus, we see that revealing one’s own token value coupled with a strategy suggestion about one’s own as well as the entire group’s strategies helps in achieving “efficient” outcomes in the situation when it is common knowledge that everyone has costs less than the ‘public’ benefit. However, in the other situation, there is a lack of use of these message categories and efficiency is also not as high. Apart from this, a closer look at the transcript of the text chat reveals that in the  $C = 1.5$  sessions there is a lot of discussion regarding lying, trust and promises, whereas, none of these terms are used when  $C = 1$ . So, in the  $C = 1.5$  sessions, there is an atmosphere of mistrust which is certainly a reason as to why subjects do not do as well in these sessions even with unrestricted text chat. A quote

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<sup>23</sup>Table 14 in the appendix compares the efficiency differences in the first ten and last ten rounds.

| Code category   | Examples   |
|---|--|
| Confirmation  | okay; cool; yes; alright; done; great; yep   |
| Own token value   | token value is 39; I have a really high value; its so low  |
| Others' token value or plan of action   | what is your token value 3?; are you going to spend 2?   |
| Strategy suggestion about others/own decision/group decision                      | I should keep my token; 1 and 2 should spend and 3 keep; everyone should spend; can I keep?  |
| Informative/explaining something to group members but not any strategy suggestion | if 2 spend then they both get 100; token values can never be higher than 100   |
| I plan to spend   | spending; I will spend   |
| I plan to keep  | keeping; I will keep   |
| Conditional statement or ambiguous/contradictory statement                        | I will spend if someone else spends; I will keep if you two spend; "I will keep" then later on says "I will spend"; I will spend or keep |
| Irrelevant/Junk   | lol; hehehe  |

Table 12: Content analysis: code categories.

| Code category   | $C = 1$ | $C = 1.5$ |
|---|---------|-----------|
| Confirmation  | 16.8    | 5.8       |
| Own token value   | 24.3    | 12.6      |
| Others' token value or plan of action   | 5.8     | 11.1      |
| Strategy suggestion about others/own decision/group decision                      | 16.2    | 6.4       |
| Informative/explaining something to group members but not any strategy suggestion | 6.9     | 19.2      |
| I plan to spend   | 11.7    | 17.4      |
| I plan to keep  | 4.4     | 8.6       |
| Conditional statement or ambiguous/contradictory statement                        | 1.5     | 3.3       |
| Irrelevant/Junk   | 12.4    | 15.6      |

Table 13: Content analysis: percentage of messages falling in the code categories.



from one of the texts from a subject aptly summarizes the situation: “this test really shows how low humans have fallen”.

## 6 Conclusion

We investigated the effect on efficiency, in a public goods game where individual endowments are private information, of non-binding pre-play communication structures differing in the richness of the message space. Neither the one-time simultaneous exchange of binary messages meant to reveal one’s intention to contribute nor the one-time numerical report of private information is enough to create a significant efficiency gain relative to the situation without any form of pre-play communication. It is only when participants are provided with the opportunity to engage in text chat in an unrestricted fashion do we find that efficiency and public good provision are significantly higher. Without a ‘common language’ there is no obvious way to interpret the binary or the numerical messages among subjects in a way that can be easily translated into coordinated actions. The natural language communication is successful even though the groups are rotated every round, so the main positive finding is not due to repeated game effects. Unrestricted chat gives the subjects the opportunity to understand and interpret each others’ intentions and messages and make credible commitments that they are willing to carry out.

A second finding is that the gains relative to the situation with no communication are much higher when it is common knowledge that everyone has costs less than the ‘public’ benefit. This is predicted by the theoretical analysis based on mechanism design, and is intuitive because in this situation the question is not whether the good should be provided but rather which of the two people in a group are going to provide it. In contrast, when some individuals have higher costs than the public benefit, individual rationality constraints impose severe restrictions on the gains from communication. In this case a group must first establish whether it is feasible for the good to be voluntarily provided, which exacerbates both the free rider problem and the incentive for individuals to truthfully reveal their private information. As a result there is more severe mis-coordination and mis-representation.

Finally, as a methodological note, this paper provides an example of how mechanism design theory can be usefully applied as a framework for understanding data from laboratory experiments of games with pre-play communication. The theoretical justification for this framework is based on the mechanism design approach to communication in games (Myerson 1986, Forges 1986), an approach that has promising applications to a wide range of other kinds of experiments, such as committee deliberation (Goeree and Yariv 2011), face-to-face bargaining, and collusion in auctions.

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## APPENDICES

### A Proofs of Propositions 1 and 2

#### Low Cost Distribution ( $C \leq 1$ )

**Proposition 1.** *If costs are uniformly distributed on  $[0, 1]$ , then the solution to (2) is  $P(c) = 1$  and  $A(c) = \frac{K}{N}$  for all  $c \in [0, 1]$ .*

**Proof.** We prove a more general version of this proposition for any admissible  $F$ . Denoting  $U(c) = P(c) - cA(c)$ , we have, from incentive compatibility that in any differentiable mechanism we must have  $U'(c) = -A(c) \geq 0$  and  $U''(c) = -A'(c) \geq 0$ , and differentiability of  $U$  and  $A$  holds almost everywhere in  $[0, 1]$ . Hence we can rewrite the optimization problem as:

$$\begin{aligned}
 & \max_{(P,A)} \int_0^C U(c) f(c) dc \\
 & \text{subject to} \\
 & A(c) = -U'(c) \quad \forall c \\
 & U''(c) \geq 0 \quad \forall c \\
 & \frac{K}{N} \int_0^C P(c) f(c) dc \leq \int_0^C A(c) f(c) dc \\
 & 0 \leq P(c) \leq 1 \quad \forall c, \quad 0 \leq A(c) \leq 1 \quad \forall c
 \end{aligned} \tag{9}$$

The first incentive constraint,  $A(c) = -U'(c)$  implies we can write

$$U(c) = U(0) - \int_0^c A(x) dx$$

We can rewrite (9) as

$$\begin{aligned}
 & \max_{(P,A)} U(0) - \int_0^C \left( \int_0^c A(x) dx \right) f(c) dc \\
 & \text{subject to} \\
 & U''(c) \geq 0 \quad \forall c \\
 & \frac{K}{N} \int_0^C P(c) f(c) dc \leq \int_0^C A(c) f(c) dc \\
 & 0 \leq P(c) \leq 1 \quad \forall c, \quad 0 \leq A(c) \leq 1 \quad \forall c
 \end{aligned} \tag{10}$$

which is equivalent to:

$$\begin{aligned}
& \max_{(P,A)} U(0) - \int_0^C A(c)dc + \int_0^C F(c)A(c)dc \tag{11} \\
& \text{subject to} \\
& U''(c) \geq 0 \quad \forall c \\
& \frac{K}{N} \int_0^C P(c)f(c)dc \leq \int_0^C A(c)f(c)dc \\
& 0 \leq P(c) \leq 1 \quad \forall c, \quad 0 \leq A(c) \leq 1 \quad \forall c
\end{aligned}$$

Let  $(P^*, A^*)$  be a solution to (11), denote  $\bar{A} = \int_0^C A^*(c)dc$ , and note that  $U^*(0) = P^*(0) - A^*(0)$ . Whatever the solution, it must be that  $A^*(\cdot)$  solves:

$$\begin{aligned}
& \max_{A(\cdot)} \int_0^C F(c)A(c)dc \\
& \text{subject to} \\
& A(0) = A^*(0) \\
& A'(c) \leq 0 \quad \forall c \\
& \int_0^C A(c)dc = \bar{A} \\
& 0 \leq A(c) \leq 1 \quad \forall c
\end{aligned}$$

Because  $F$  is nonnegative and strictly increasing and  $A$  is required to be nonincreasing, this immediately implies that  $A'^* = 0$  and hence  $A^*(c) = \bar{A}$  for all  $c$ . Because  $A^*$  is flat, incentive compatibility implies that  $P^*$  is also flat, with  $P^*(c) = P^*(0)$  for all  $c$ . Furthermore, it must be that  $\bar{A}^*$  is as small as possible, subject to the feasibility constraint, implying immediately that  $\frac{K}{N} \int_0^C P^*(c)f(c)dc = \int_0^C A^*(c)f(c)dc$ . Hence, the problem reduces to finding the optimal flat mechanism that is also budget balanced, which trivially implies  $P^*(c) = 1$  for all  $c$  and  $A^*(c) = \frac{K}{N} \forall c$ . In other words, the public good is always provided, and exactly  $K$  individuals are randomly selected to contribute. Observe that ex post individual rationality is satisfied and also that implementability of the reduced form mechanism is trivial. Thus, the ex ante efficient mechanism does not use any information about types. It completely solves the coordination problem of over- and under-contribution, and the free rider problem but is completely unable to resolve the informational source of cost inefficiency which would require low cost types to contribute more often than high cost types.

We conjecture that the requirement that F be admissible is stronger than is needed. Perhaps all that is needed is that there are no mass points.

**High cost distribution:**  $C = 1.5$

**Proposition 2.** *If costs are uniformly distributed on  $[0, 1.5]$ ,  $K = 2$ , and  $N = 3$ , then the solution to (3) is given by:*

$$\begin{aligned} c^* &= 0.75 \\ P(c) &= 0.75 \quad \forall c \in [0, c^*] \\ &= 0.25 \quad \forall c \in [c^*, 1.5] \\ A(c) &= 0.67 \quad \forall c \in [0, c^*] \\ &= 0 \quad \forall c \in [c^*, 1.5] \end{aligned}$$

**Proof.** As for Proposition 2, we provide a more general proof for the case where  $K, N$  are arbitrary integers with  $1 \leq K \leq N$ .

Because IC implies  $A(c) = -U'(c) \quad \forall c$ , we have:

$$\begin{aligned} U(c) &= U(1.5) + \int_c^{1.5} A(x) dx \\ &= \underline{P} + \int_c^{\max\{c, c^*\}} \hat{A}(x) dx \end{aligned}$$

so the optimization problem can be rewritten as:

$$\max_{(\hat{P}, \hat{A}, \underline{P}, c^*)} \underline{P} + \int_0^{1.5} \left( \int_c^{\max\{c, c^*\}} \hat{A}(x) dx \right) \frac{1}{1.5} dc \quad (12)$$

subject to

$$\begin{aligned} U''(c) &\geq 0 \quad \forall c \\ \frac{K}{N} \left\{ \underline{P} \left[ 1 - \frac{c^*}{1.5} \right] + \int_0^{c^*} \hat{P}(c) \frac{1}{1.5} dc \right\} &\leq \int_0^{c^*} \hat{A}(c) \frac{1}{1.5} dc \\ 0 &\leq \hat{P}(c) \leq \underline{P} \quad \forall c, \quad 0 \leq \hat{A}(c) \leq 1 \quad \forall c \in [0, c^*] \end{aligned}$$

where  $\frac{1}{1.5}$  is just the density function of the cost distribution. This is equivalent to:

$$\begin{aligned}
& \max_{(\hat{P}, \hat{A}, \underline{P}, c^*)} \underline{P} + \int_0^{c^*} \frac{c}{1.5} \hat{A}(c) dc & (13) \\
& \text{subject to} \\
& U''(c) \geq 0 \quad \forall c \\
& \frac{K}{N} \left\{ \underline{P} \left[ 1 - \frac{c^*}{1.5} \right] + \int_0^{c^*} \hat{P}(c) \frac{1}{1.5} dc \right\} \leq \int_0^{c^*} \hat{A}(c) \frac{1}{1.5} dc \\
& 0 \leq \hat{P}(c) \leq \underline{P} \quad \forall c, \quad 0 \leq \hat{A}(c) \leq 1 \quad \forall c \in [0, c^*]
\end{aligned}$$

Let  $(\hat{P}^*, \hat{A}^*, \underline{P}^*, c^*)$  be a solution to (13), denote  $\bar{A} = \int_0^{c^*} \hat{A}(c) \frac{1}{1.5} dc$ . If this is optimal, then it must be that the budget constraint holds with equality. That is:

$$\frac{K}{N} \left\{ \underline{P}^* \left[ 1 - \frac{c^*}{1.5} \right] + \int_0^{c^*} \hat{P}^*(c) \frac{1}{1.5} dc \right\} = \bar{A}^*$$

If not,  $\underline{P}$  can be increased without violating any constraints and increases the objective function,  $\underline{P} + \int_0^{c^*} \frac{c}{1.5} \hat{A}(c) dc$ . This implies that whenever the public good is produced, it is produced with exactly  $K$  contributions. Second, as in the case studied earlier, with  $C \leq 1$ , for any  $\bar{A}$ ,  $\hat{A}^*(c)$  must solve:

$$\begin{aligned}
& \max_{\hat{A}(\cdot)} \int_0^{c^*} \frac{c}{1.5} \hat{A}(c) dc \\
& \text{subject to} \\
& \hat{A}'(c) \leq 0 \quad \forall c \in [0, c^*] \\
& \int_0^{c^*} \hat{A}(c) dc = \bar{A} \\
& 0 \leq \hat{A}(c) \leq 1 \quad \forall c \in [0, c^*]
\end{aligned}$$

Because  $F$  is nonnegative and strictly increasing and  $\hat{A}$  is required to be nonincreasing, this immediately implies that  $\hat{A}^{*'} = 0$  and hence  $\hat{A}^*(c) = \bar{A}^*$  for all  $c \in [0, c^*]$ . Because  $\hat{A}^*$  is flat, incentive compatibility implies that  $\hat{P}^*$  is also flat, with  $\hat{P}^*(c) = \bar{P}^*$  for all  $c \in [0, c^*]$ . Next observe that, given any  $c^*$ ,  $\underline{P}$  is maximized by producing the good whenever at least  $K$  individuals have a cost  $c \in [0, c^*]$ . Budget balance then implies that whenever this is the case, the individuals share the cost equally. Hence the mechanism looks qualitatively very similar to the optimal mechanism when  $C \leq 1$ . In the direct version of this mechanism, everyone reports their cost; if at least  $K$  individuals report a cost

less than or equal to  $c^*$ , the public good is produced and exactly  $K$  of these “low cost” individuals are randomly selected to contribute. Otherwise the public good is not produced at all. Finally, the critical cost,  $c^*$ , is pinned down by incentive constraint on the  $c^*$  type, who must be indifferent between reporting  $c^*$  with an expected payoff of  $\bar{P}^* - c^* \bar{A}^*$  and reporting some higher cost and getting an expected payoff of  $\underline{P}^*$ . Thus,  $c^*$  is characterized by:

$$\bar{P}^* - c^* \bar{A}^* = \underline{P}^* \quad (14)$$

Where, by the characterization above, we have:

$$\begin{aligned} \bar{P}^* &= \sum_{j=K-1}^{N-1} \binom{N-1}{j} \left[ \frac{c^*}{1.5} \right]^j \left[ 1 - \frac{c^*}{1.5} \right]^{N-1-j} \\ \underline{P}^* &= \sum_{j=K}^{N-1} \binom{N-1}{j} \left[ \frac{c^*}{1.5} \right]^j \left[ 1 - \frac{c^*}{1.5} \right]^{N-1-j} \\ \bar{A}^* &= \sum_{j=K-1}^{N-1} \frac{K}{j+1} \binom{N-1}{j} \left[ \frac{c^*}{1.5} \right]^j \left[ \frac{c^*}{1.5} \right]^{N-1-j} \end{aligned} \quad (15)$$

If there are multiple values of  $c^* \in [0, 1)$  that solve 14, then the optimal mechanism corresponds to the highest such value of  $c^*$ , because it leads to the highest possible value of  $\underline{P}$ .<sup>24</sup>

### Solution for experimental parameters: K=2, N=3

Substituting into (15) the specific values  $K = 2$ ,  $N = 3$ , and denoting  $q = \frac{c^*}{1.5}$ , we get

$$\begin{aligned} \bar{P}^* &= q^2 + 2q(1 - q) \\ \underline{P}^* &= q^2 \\ \bar{A}^* &= \frac{2}{3}q^2 + 2q(1 - q) \end{aligned}$$

where  $q = \frac{c^*}{1.5}$ . Solving for  $q$  using (14) gives  $q = 0.5$ . Hence  $c^* = 0.75$ ,  $\underline{P}^* = 0.25$ ,  $\bar{P}^* = 0.75$  and  $\bar{A}^* = \frac{2}{3}$ . The ex ante probability the public good will be provided is 0.50. This can also be implemented in the chat communication or in the token revelation communication protocols.

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<sup>24</sup>We conjecture that the above proof extends to non-uniform distributions. For similar reasons to proposition 1, the argument above probably goes through for any continuously differentiable distribution function  $F$  on  $[0, C]$ , where  $0 < C \leq 1$ ,  $F(0) = 0$  and  $F(C) = 1$ . However, the existence of the binding ex post individual rationality constraint lead to some technical problems that will require stronger assumptions about  $F$ .



## B Sample Instructions (for $C = 1$ )

Thank you for agreeing to participate in this group decision making experiment. During the experiment we require your complete, undistracted attention, and ask that you follow instructions carefully. You should not open other applications on your computer, chat with other students, or engage in other distracting activities, such as using your phone, reading books, etc.

You will be paid for your participation in cash, at the end of the experiment. Different participants may earn different amounts. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

The entire experiment will take place through computer terminals, and all interaction between you will take place through the computers. It is important that you not talk or in any way try to communicate with other participants during the experiment, except as instructed.

We will start with a brief instruction period. During the instruction period, you will be given a complete description of the experiment and will be shown how to use the computers. If you have any questions during the instruction period, raise your hand and your question will be answered out loud so everyone can hear. If you have any questions after the experiment has begun, raise your hand, and an experimenter will come and assist you.

You will make choices over a sequence of 20 matches. In each match, you will be assigned to a group with two other participants in the room. In every match, you and the two other participants you are matched with each makes a single decision. Your earnings for that match will depend on all three group members' decisions, but are completely unaffected by the decisions made by participants assigned to other groups. We will explain exactly how these payoffs are computed in a minute.

At the end of the session, you will be paid the sum of what you have earned in all matches, plus the show-up fee of \$ 5. Everyone will be paid in private and you are under no obligation to tell others how much you earned. Your earnings during the experiment are denominated in points. At the end of the experiment you will be paid \$ 1 for every 100 points you have earned.

Every match proceeds as follows. At the beginning of each match, we randomly divide you into 3-member groups called committees. The committees are completely independent of each other and payoffs and decisions in one committee have no effect on payoffs and decisions in other committees. Each member has a single token and can either spend or keep that token. Each member is also assigned a private token value, which is equally likely to be any amount of points between 1 and 100 (150 in  $C = 1.5$  instructions). Token value assignments are completely independent across members, across committees, and across matches. Thus, your own token value tells you absolutely nothing about the token value of the other members, and has no effect on any future token values that will be assigned

to you or anyone else.

Payoffs are computed as follows. If you keep your token you earn your token value in that match plus you earn 100 points if both other members of your committee decide to spend their tokens. If you choose to spend your token, then you earn 100 points if at least one other member of your group spends their token, and you earn 0 points if no other member of your group spends their token. This is summarized in the following table.

| Your Decision | #Others Spending | Your Earnings          |
|---------------|------------------|------------------------|
| SPEND         | 0                | 0                      |
|               | 1                | 100                    |
|               | 2                | 100                    |
| KEEP          | 0                | YOUR TOKEN VALUE       |
|               | 1                | YOUR TOKEN VALUE       |
|               | 2                | YOUR TOKEN VALUE + 100 |

[The following paragraph only in the ‘No Communication’ treatments.] Every match you are prompted to make your choice to either keep or spend your token. When everyone has made a choice, the outcome and the choices of the other members of your committee are revealed, and this determines your earnings for the match.

[The following two paragraphs only in the ‘Binary Communication’ treatments.] Before anyone makes a spending decision, each of you will have an opportunity to give the other members of your committee some indication of what your spending decision might be. There are exactly two messages which you can send. They are:

MESSAGE A: “I INTEND TO SPEND MY TOKEN”

MESSAGE B: “I INTEND TO KEEP MY TOKEN”

Please remember that these are only messages and are not binding in any way. When the message stage ends, you are told the intent messages of the others in your committee and the decision stage begins wherein you are prompted to make your choice to either keep or spend your token. This decision is binding. When everyone has made a choice, the outcome and the choices of the other members of your committee are revealed, and this determines your earnings for the match.

[The following two paragraphs only in the ‘Token Revelation’ treatments.] Before anyone makes a spending decision, your committee has a 20 seconds message stage, during which you are allowed to

send a message to the other members of your committee. This message can only be an integer between 1 and 100 (150 in  $C = 1.5$  instructions) and you are allowed to send only one such message. The integer value you send are seen by both other members of your committee. In the situation where you do not send any message, it will be shown as a “question mark” to other members of your committee at the end of the message stage.

When the message stage ends, the decision stage begins wherein you are prompted to make your choice to either keep or spend your token. When everyone has made a choice, the outcome and the choices of the other members of your committee are revealed, and this determines your earnings for the match.

[The following two paragraphs only in the ‘Chat’ treatments.] Before anyone makes a spending decision, your committee has a 60 seconds discussion period, during which you are allowed to send messages to the other members of your committee. The messages you send are seen by both other members of your committee. The messages must conform to the following rules: (1) Your messages must be relevant to the experiment. Do not engage in social chat or use emoticons. (2) You are not permitted to send messages intended to reveal your identity. (3) The use of threatening or offensive language, including profanity, is not permitted. (4) Do not send blank or nonsense messages.

When the discussion period ends, the decision stage begins wherein you are prompted to make your choice to either keep or spend your token. When everyone has made a choice, the outcome and the choices of the other members of your committee are revealed, and this determines your earnings for the match.

When all committees have finished the first match, we then go to the next match. You will be randomly re-matched into new 3-person committees and everyone is independently and randomly assigned a new token value between 1 and 100 (150 in  $C = 1.5$  instructions). Every match proceeds according to exactly the same rules as described above.

## C Additional Tables

The following tables expand the analysis presented in the body of the paper, where applicable, to include data from the early rounds 1-10.

| Rounds                      | No Comm.        | Binary Comm.   | Token Revelation | Chat              |
|-----------------------------|-----------------|----------------|------------------|-------------------|
| <u><math>C = 1</math></u>   |                 |                |                  |                   |
| 1-10                        | 113.2<br>(15.7) | 89.7<br>(14.0) | 95.8<br>(14.8)   | 176.8**<br>(11.9) |
| 11-20                       | 88.0<br>(15.3)  | 80.2<br>(14.7) | 101.5<br>(14.6)  | 221.1***<br>(7.1) |
| All rounds                  | 100.6<br>(10.9) | 84.9<br>(10.1) | 98.6<br>(10.4)   | 198.9***<br>(7.2) |
| <u><math>C = 1.5</math></u> |                 |                |                  |                   |
| 1-10                        | 67.0<br>(14.0)  | 82.0<br>(13.8) | 55.1<br>(13.8)   | 48.5<br>(12.4)    |
| 11-20                       | 39.6<br>(12.4)  | 58.7<br>(13.4) | 42.1<br>(11.9)   | 83.4***<br>(13.9) |
| All rounds                  | 53.3<br>(9.4)   | 70.3<br>(9.6)  | 48.6<br>(9.1)    | 66.0<br>(9.4)     |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. These significance levels are for one-tailed Mann-Whitney tests of difference in the net earnings across the communication treatment and 'No Communication'.

Table 14: Average group earnings net of token values. Standard errors in parentheses.

| Rounds                      | No Comm.   | Binary Comm. | Token Revelation | Chat          |
|-----------------------------|------------|--------------|------------------|---------------|
| <u><math>C = 1</math></u>   |            |              |                  |               |
| 1-10                        | 54.3 (70)  | 47.5 (80)    | 48.8 (80)        | 85.0*** (60)  |
| 11-20                       | 42.9 (70)  | 41.3 (80)    | 50.0 (80)        | 98.3*** (60)  |
| All rounds                  | 48.6 (140) | 44.4 (160)   | 49.4 (160)       | 91.7*** (120) |
| <u><math>C = 1.5</math></u> |            |              |                  |               |
| 1-10                        | 38.8 (80)  | 43.8 (80)    | 38.8 (80)        | 31.3 (80)     |
| 11-20                       | 27.5 (80)  | 37.5 (80)    | 25.0 (80)        | 42.5** (80)   |
| All rounds                  | 33.1 (160) | 40.6 (160)   | 31.9 (160)       | 36.9 (160)    |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. These significance levels are for difference in proportions z-tests in the public good provision across the communication treatment and ‘No Communication’.

Table 15: Frequency of public good provision. Number of observations in parentheses.

| Rounds                      | No Comm.         | Binary Comm.      | Token Revelation | Chat                |
|-----------------------------|------------------|-------------------|------------------|---------------------|
| <u><math>C = 1</math></u>   |                  |                   |                  |                     |
| 1-10                        | 37.1, 12.9 (70)  | 36.3, 15.0 (80)   | 47.5, 6.3* (80)  | 8.3***, 11.7 (60)   |
| 11-20                       | 45.7, 14.3 (70)  | 41.3, 6.3* (80)   | 40.0, 11.3* (80) | 1.7***, 1.7*** (60) |
| All rounds                  | 41.4, 13.6 (140) | 38.8, 10.6 (160)  | 43.8, 8.8* (160) | 5.0***, 6.7** (120) |
| <u><math>C = 1.5</math></u> |                  |                   |                  |                     |
| 1-10                        | 46.3, 6.3 (80)   | 30.0**, 6.3 (80)  | 47.5, 5.0 (80)   | 45.0, 3.8 (80)      |
| 11-20                       | 47.5, 7.6 (80)   | 38.8, 2.5 (80)    | 40.0, 7.5 (80)   | 30.0**, 5.0 (80)    |
| All rounds                  | 46.9, 6.9 (160)  | 34.4**, 4.4 (160) | 43.8, 6.3 (160)  | 37.5**, 4.4 (160)   |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. These significance levels are for difference in proportions z-tests across the communication treatment and ‘No Communication’.

Table 16: Percentage of wasteful contributions: first entry is for exactly one person contributing and second entry is for all three members in a group contributing. Number of observations in parentheses.

| Rounds                      | No Comm.  | Binary Comm. | Token Revelation | Chat          |
|-----------------------------|-----------|--------------|------------------|---------------|
| <u><math>C = 1</math></u>   |           |              |                  |               |
| 1-10                        | 60.5 (38) | 42.1 (38)    | 61.5 (39)        | 74.5 (51)     |
| 11-20                       | 56.7 (30) | 57.6 (33)    | 65.0 (40)        | 86.4*** (59)  |
| All rounds                  | 58.8 (68) | 49.3 (71)    | 63.3 (79)        | 80.9*** (110) |
| <u><math>C = 1.5</math></u> |           |              |                  |               |
| 1-10                        | 64.5 (31) | 71.4 (35)    | 67.7 (31)        | 80.0 (25)     |
| 11-20                       | 68.2 (22) | 70.0 (30)    | 55.0 (20)        | 79.4 (34)     |
| All rounds                  | 66.0 (53) | 70.8 (65)    | 62.7 (51)        | 79.7 (59)     |

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. These significance levels are for difference in proportions z-tests across the communication treatment and ‘No Communication’.

Table 17: Percentage of two lowest costs contributing. Number of observations where the public good is provided is in parentheses.